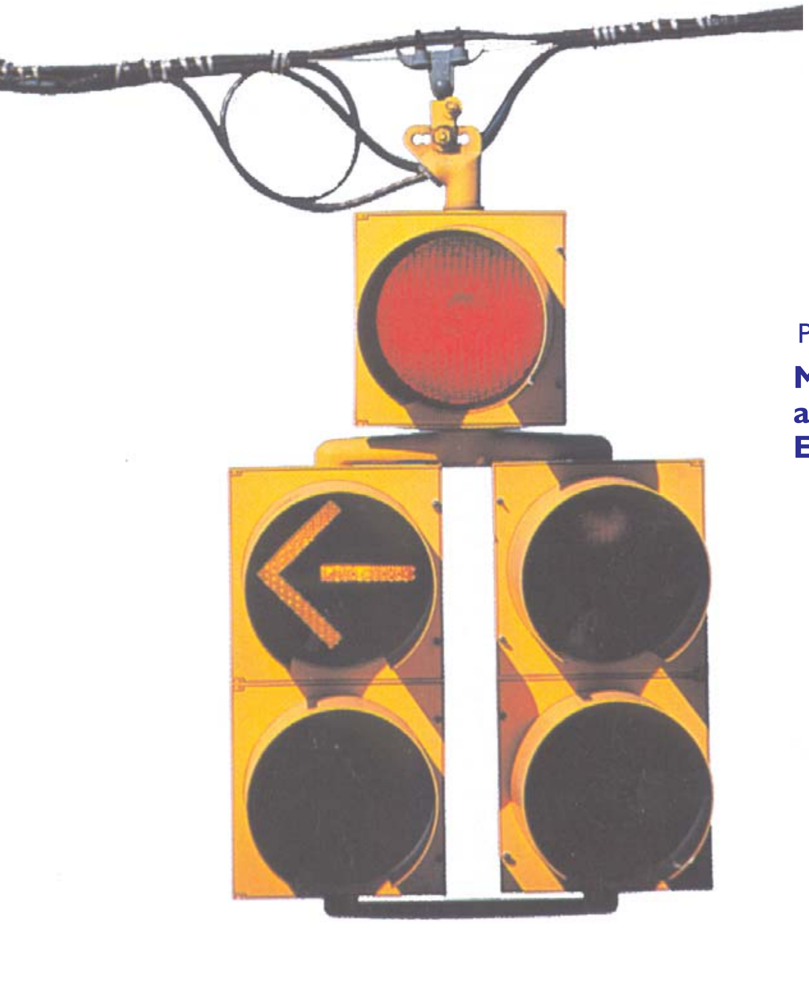
Traffic Signal Timing and Phasing Policy



Prepared for:

Metropolitan Government of Nashville and Davidson County Department of Public Works, Engineering Division

October 1, 2004

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I. INTRODUCTION

The Metropolitan Government of Nashville and Davidson County Department of Public Works (MPW) – Engineering Division has adopted a set of traffic signal timing and phasing policies which are to be implemented at signalized intersections under their jurisdiction. The purpose of this policy is to establish standard practices and operational procedures for traffic signal timing parameters to be used by MPW staff and consulting engineers performing signal timing services for MPW. This policy is in no way in conflict with the Federal Highway Administration's *Manual on Uniform Traffic Control Devices* (MUTCD). Should a conflict arise, the MUTCD shall prevail.

The guidelines referenced in this document – *Traffic Signal Timing and Phasing Policy* – are to be implemented at new traffic signal installations, traffic signal upgrades, and along signalized corridors as they are re-timed. The adoption of this policy does not imply that each and every traffic signal under the jurisdiction of Metro Nashville-Davidson County Department of Public Works will automatically comply with these new guidelines. Rather, traffic signal settings will be updated along signalized corridors throughout Metro Nashville-Davidson County as they are re-timed.

This policy has been established to provide guidance on various signal timing parameters. However, signal timing should be evaluated for all situations independently based upon standard traffic engineering principles and local intersection characteristics. Necessary adjustments should be made to meet the traffic conditions at each individual signalized intersection. This policy should serve to provide consistent, safe, and efficient control of traffic signals within Metro Nashville-Davidson County.

Prior to developing this document, research was performed on federal, state, and professional organization standards/guidelines as well as interviews with other selected peer public agencies throughout the United States (primarily the Southeast). The following groups were either interviewed or researched prior to the development of this document:

- Federal Highway Administration (FHWA)
- Institute of Transportation Engineers (ITE)
- Tennessee Department of Transportation (TDOT)
- North Carolina Department of Transportation (NCDOT)
- South Carolina Department of Transportation (SCDOT)
- Kentucky Transportation Cabinet (KTC)
- City of Memphis, Tennessee
- City of Knoxville, Tennessee
- City of Chattanooga, Tennessee
- City of Atlanta, Georgia
- City of Birmingham, Alabama
- City of Newport News, Virginia
- Lexington-Fayette Urban County Government, Kentucky
- Louisville-Jefferson County Metropolitan Government, Kentucky
- Miami-Dade County Government, Florida
- City of Fort Worth, Texas
- City of Vacaville, California

II. VEHICLE CLEARANCE INTERVALS

The MUTCD requires that vehicle clearance intervals consist of a required yellow change interval and an optional red clearance interval. The MUTCD[1] defines both the yellow change and red clearance intervals as:

> *Yellow Change Interval – the first interval following the green interval during which the yellow signal indication is displayed.*
>
> *Red Clearance Interval – an optional interval that follows a yellow change interval and precedes the next conflicting green interval.*

In Section 4D.10, the MUTCD also states the following:

> *A yellow signal indication shall be displayed following every CIRCULAR GREEN or GREEN ARROW signal indication. The exclusive function of the yellow change interval shall be to warn traffic of an impending change in the right-of-way assignment.*

Per the MUTCD and consistent with the *Uniform Vehicle Code* (UVC), MPW will provide a yellow change interval and has chosen to include an all red clearance interval following each circular green or green arrow signal indication at every signalized intersection under their jurisdiction. The UVC[2] defines the yellow indication and the red indication as follows:

> *Yellow Indication – Vehicular traffic facing a steady circular yellow or yellow arrow indication is thereby warned that the related green movement is about to end or that a red indication may be exhibited immediately thereafter. A circular yellow or yellow arrow indication, as appropriate, shall be displayed immediately after every circular green or green arrow interval.*
>
> *Red Indication – Vehicular traffic facing a steady circular red or red arrow indication alone shall stop at a clearly marked stop line, or if none, before entering the marked crosswalk on the near side of the intersection, or if none, before entering the intersection, and shall remain stopped at the intersection until an indication to proceed is shown.*

For the purposes of this policy, the yellow indication will be defined as the yellow clearance interval. The purpose of the yellow clearance interval is to warn approaching traffic of the imminent change in the assignment of right-of-way.

The red indication as described above in the UVC does not necessarily coincide with the definition of the red clearance interval. All signalized intersections shall provide a red indication following a yellow clearance interval (yellow indication) per the MUTCD and UVC. However, it is not mandated that a red clearance interval be provided following each signalized vehicle movement. However, MPW has decided to require an all red clearance interval following each yellow clearance interval. The red clearance interval is an all red indication for every signalized vehicle movement which follows each yellow clearance interval. Prior to servicing the next signalized vehicle movement, an all red indication is provided for each signalized intersection approach/movement. The red clearance interval is used to allow vehicles to clear the intersection before opposing traffic receives a green indication.

The calculation of vehicle clearance intervals will be based upon the criteria set forth in the Institute of Transportation Engineer's (ITE) *Manual on Traffic Signal Design*[3]. The following formula provides a total clearance interval value:

$$VCI = t + V/(2a + 64.4g) + (W + L)/V$$

Where:

VCI	=	total vehicle clearance interval (yellow change + red clearance), seconds
t	=	perception-reaction time, seconds
V	=	approach speed, feet/second
a	=	deceleration rate, feet/second^2
g	=	percent of grade divided by 100 (+ for upgrade, - for downgrade)
W	=	width of intersection, feet
L	=	length of vehicle, feet

Typically, the yellow clearance interval is calculated using the first two terms of the above equation, [$t + V/(2a + 64.4g)$], and the red clearance interval is calculated using the third term of the equation, [$(W + L)/V$]. A series of tables summarizing the theoretical minimum *VCI* calculations are provided in the **Appendix** of this document.

Some of these variables are site specific such as intersection width, percent of grade, and approach speed. However, the others are not. Typical values for the non-site specific variables as suggested in the ITE Informational Report *Determining Vehicle Signal Change and Clearance Intervals*[4] are:

t	=	1 second
a	=	10 feet/second^2
L	=	20 feet

However, the traffic engineer should use engineering judgment when determining whether or not the typical values apply for a given signalized intersection. If local circumstances warrant something different than the typical values, then the traffic engineer should use values based upon local circumstances.

Percent of grade, *g*, will only be considered when the intersection approach grade exceeds +/- five (5) percent. This is because approach grades less than +/- five (5) percent have an effect of less than 0.5 seconds and is within typical interval rounding.

The intersection width, *W*, for through movements shall be measured from the approach stop bar to the projection of the departure face of curb (FOC)/edge of traveled way (EOTW). For left-turn movements, this distance shall be measured along the vehicle turning path from the approach stop bar to the projection of the departure FOC/EOTW. **Figure 1** below depicts these measurements.

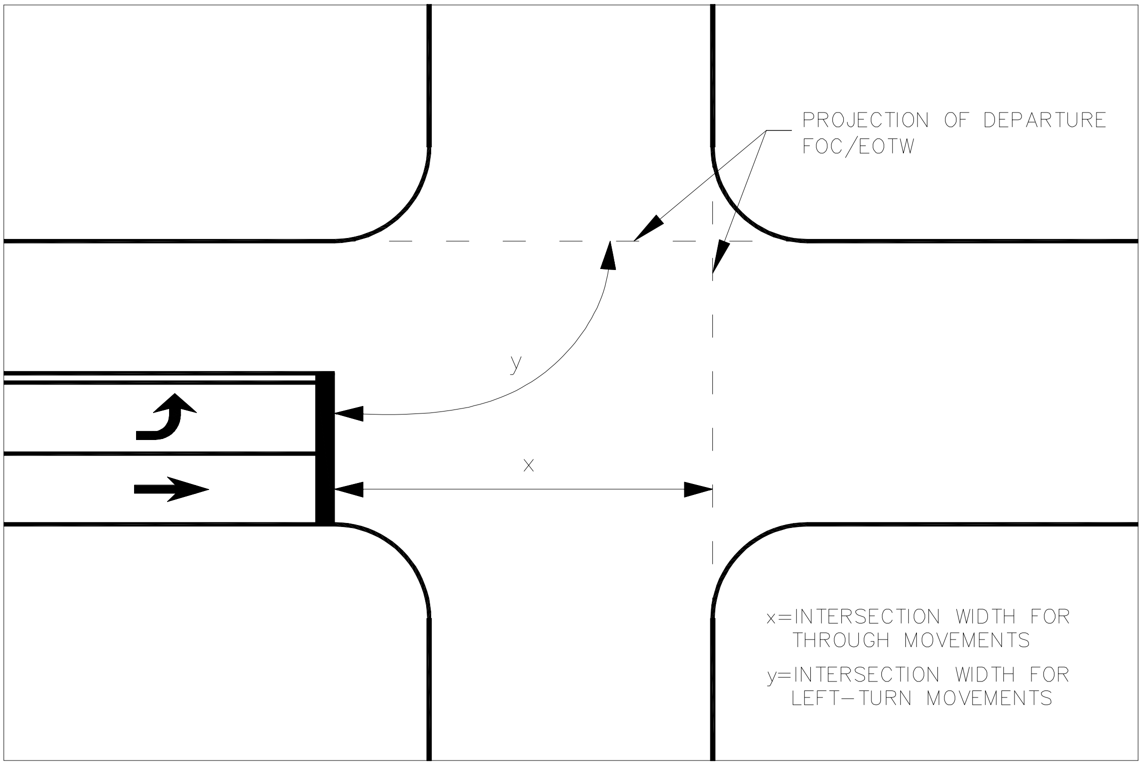

Figure 1. Intersection Widths for Vehicle Clearance Interval Calculations

Once the total clearance interval, *VCI*, has been calculated, MPW has chosen acceptable ranges for both yellow change and red clearance intervals. **Table 1** below illustrates these ranges.

Table 1
Acceptable Ranges for Vehicle Clearance Intervals

Total Vehicle Clearance Interval (seconds)		**Yellow Change Interval (seconds)**		**Red Clearance Interval (seconds)**	
Minimum	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
4	9	3	5	1	4

Total clearance intervals should be rounded to the nearest half second if possible. Although these acceptable ranges will accommodate the majority of the signalized intersections under MPW jurisdiction, there may be instances where the maximum thresholds need to be adjusted. Any values greater than those tabulated above should be justified via an engineering study. All total clearance interval values shall be approved by MPW Traffic Engineering staff prior to implementation.

III. PEDESTRIAN CONTROL FEATURES

There are a number of pedestrian-related items that are covered in this portion of the policy. They include recommended pedestrian walking speeds, minimum pedestrian walk intervals for pedestrian signal phasing, guidelines for pedestrian clearance intervals, and recommendations for the use of pedestrian push buttons.

Minimum Pedestrian Walk Interval

The MUTCD in Section 4E.10 states the following in reference to pedestrian walk intervals for intersections with pedestrian phasing:

> *Guidance: Except as noted in the Option, the walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins.*
>
> *Option: If pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used.*

Using the MUTCD guidance statement, signalized intersections that have pedestrian phasing under MPW jurisdiction will have a preferred minimum of seven (7) seconds of walk time. However, if pedestrian volumes and other intersection characteristics do not require a seven (7)-second walk interval, walk intervals as low as five (5) seconds may be used. Engineering judgment shall be used when determining if the absolute minimum of a five (5)-second walk interval should be used.

Pedestrian walk intervals greater than seven (7) seconds may be necessary in areas with heavy pedestrian volumes, a larger percentage of elderly, elementary school-aged, and/or handicapped pedestrians, or other situations deemed necessary by MPW staff.

Pedestrian Walking Speed

The typical pedestrian walking speed used to determine pedestrian phasing shall be four (4) feet per second (fps) as supported by the MUTCD. However in areas with significant percentages of elderly pedestrians or elementary-aged children a walking speed of 3.5 fps should be considered. Furthermore, there may be unique instances where walking speeds even lower than 3.5 fps may be deemed appropriate by MPW staff.

Pedestrian Clearance Interval

The MUTCD states the following in Section 4E.10 concerning pedestrian clearance times:

> *Guidance: The pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder during the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 1.2 m (4 ft) per second, to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait. Where pedestrians who walk slower than 1.2 m (4 ft) per second, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 1.2 m (4 ft) per second should be considered in determining the pedestrian clearance time.*

> *Option: The pedestrian clearance time may be entirely contained within the vehicular green interval, or may be entirely contained within the vehicular green and yellow change intervals.*

Per the MUTCD, the calculation of the pedestrian clearance interval is as follows:

$$PCI = D/V$$

Where:

PCI	=	pedestrian clearance interval, seconds
D	=	pedestrian crossing distance, feet
V	=	pedestrian walking speed, feet/second (as discussed above)

The pedestrian crossing distance, *D*, shall be measured from face of curb to face of curb (or from EOTW to EOTW, if no curbing exists).

The pedestrian clearance interval shall be timed concurrently with the vehicle green interval and utilize three (3) seconds of the vehicle yellow change interval. If pedestrian signal heads are present they shall display a flashing don’t walk (FDW) indication during the vehicle green interval, yet change to a steady don’t walk (DW) indication during the vehicle yellow change interval.

Pedestrian Push Button Usage

Pedestrian push button actuation is recommended for pedestrian phases that cross the ‘main street’ approaches so that ‘side street’ vehicle phases do not have to accommodate pedestrian timings unless they are actuated via a pedestrian push button.

The need for push button actuation to cross side street approaches shall be determined via engineering judgment by the MPW traffic engineer.

For the purposes of determining main street approaches in reference to pedestrian timings, the main street approaches will be considered the signalized approaches that are coordinated and are therefore non-actuated. If a traffic signal is pre-timed or fully-actuated, the differentiation between main street and side street does not apply for this situation.

Walk Rest Modifier Option

During main street vehicle signal phases that are non-actuated, there are often situations where the vehicle split is significantly larger than the required pedestrian walk and clearance intervals. Rather than increasing the pedestrian clearance interval to accommodate the additional time available, MPW staff will allow the signal controller to extend the length of the pedestrian walk interval. There are however, situations where this option, known as the walk rest modifier, should not be allowed. Such applications where the walk rest modifier should not be utilized include the following: (a) cases where right-turn volumes are heavy across the pedestrian crossing area, (b) cases where permissive left-turn volumes are heavy across the pedestrian crossing area, and (c) any other cases where MPW staff has determined that the walk rest modifier option should not be implemented.

IV. MINIMUM VEHICLE GREEN TIMES

Minimum vehicle green times should be short enough so that green time is not wasted, yet not so short such that motorists unexpectedly see the yellow change interval while entering the intersection and become confused. The minimum times documented in this section of the policy are the minimum allowed which does not suggest that all signalized intersections will utilize these minimum values. Greater minimum green times are allowed; however values lower than these mentioned below are not recommended.

In addition, the percentage of trucks should also be reviewed on an intersection-by-intersection basis since a high percentage of trucks may necessitate increasing the minimum green time controller setting.

Maximum green time setting are not discussed in this policy since they vary significantly by location and are based on signal operation, vehicle demand, and other operational characteristics.

Minimum Green Times for Left-turn Phases

A minimum green time setting of four (4) seconds is allowed for left-turn phases.

Minimum Green Times for Side Street Through Phases

A minimum green time setting of seven (7) seconds is allowed for side street phases.

Minimum Green Times for Main Street Through Phases

A minimum green time setting of ten (10) seconds is allowed for main street through phases.

Main Street and Side Street Definitions

It is often obvious, when comparing approach geometry, traffic volumes, road classification and/or route continuity, which roadway is considered the ‘main street’ and which is considered the ‘side street’. However, there are instances where there is no clear cut distinction between the two. Some intersections include two main streets. For the purposes of selecting minimum green time settings, the following definition will apply for determining whether or not a main street approach exists. Multi-lane approaches – that is intersection approaches with two (2) or more through lanes – are to be considered as main street approaches.

V. LEFT-TURN SIGNAL PHASING GUIDELINES

Left-turn phasing guidelines as discussed in the ITE *Traffic Engineering Handbook*[5] are to be used for assistance in assessing the need for left-turn phasing at signalized intersections under MPW jurisdiction. There are two Transportation Research Record documents suggested by ITE for traffic engineers to consider where determining the need for some form of protection for left-turn phases. They are:

> From J. E. Upchurch. Guidelines for Selecting Type of Left-turn Phasing. In *Transportation Research Record* 1069, Transportation Research Board, National Research Council, Washington, D.C., Figure 5, p. 37. Reproduced with permission.
>
> From Asante, S. A., S. A. Ardekani, and J. C. Williams. Selection Criteria for Left-Turn Phasing and Indication Sequence. In *Transportation Research Record* 1421, Transportation Research Board, National Research Council, Washington, D.C., 1993, Figure 4, p. 17. Reproduced with permission.

Refer to the **Appendix** of this document for copies of these flowcharts and graphs referenced above. These guidelines shall be used as a tool for determining the need for left-turn phasing at signalized intersections along with engineering judgment by the traffic engineer.

In addition to the guidelines referenced above, there are two additional guidelines that are to be adopted as MPW policy:

Exclusive/permissive left-turn signal phasing is allowed when three (3) opposing through lanes exist as long as there is no accident experience problem and/or sight distance issue that would hamper the safety of permissive left-turn movements.

Exclusive left-turn signal phasing shall be installed where multiple left-turn lanes exist.

Protected/Permissive Left-Turn Phase Operation

Phasing for eight-phase signal controllers should prohibit a phase change from main street green to a main street left-turn phase if it the left-turn phase operates protected/permissive. In the absence of a side street actuation, the signal controller should remain in main street green to allow left-turn movements to occur on the permissive green.

VI. SPLIT-PHASE TIMING OPERATION GUIDELINES

The term split-phase signal operation describes a signal phasing sequence where one approach is given exclusive right-of-way into the intersection followed by the opposing approach being provided exclusive right-of-way into the intersection. This operation eliminates left-turn conflicts; however, it is often described by traffic engineers as an inefficient signal phasing option since the entire intersection is given a red indication to service only one of the four signalized approaches. Nonetheless, there are situations where its use should be considered. For traffic signals under the jurisdiction of MPW staff, the following situations may necessitate the need for split-phase timing operation:

- Where offset approaches exist that may cause motorist conflicts/confusion if permissive phasing were implemented.
- Where intersection width prevents opposing left turn movements from operating concurrently. Prior to implementing split-phase operation due to this geometric limitation, the installation of lead-lag phasing should also be considered.
- When an accident problem exists between left-turn and through movement conflicts that has not been successfully remedied via other operational improvements.
- Where a sizeable volume imbalance exists on the side street approaches.
- Where a second left-turn lane is needed but must be shared with a through movement lane.
- Where the need to serve the left-turn volume is relatively close to the time needed to serve the through movement volume.

For each case, a capacity analysis should be performed comparing split-phase timing operation versus other signal phasing options prior to implementation.

REFERENCES

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices.* Washington, DC: U.S. Department of Transportation, 2003.

2. National Committee on Uniform Traffic Laws and Ordinances. *Uniform Vehicle Code*. As revised through Supplement III of 1979. Washington, DC: National Committee on Uniform Traffic Laws and Ordinances, 1979.

3. Institute of Transportation Engineers. *Manual on Traffic Signal Design,* 2nd Ed. Washington, DC: James H. Kell and Iris J. Fullerton, ed. Institute of Transportation Engineers, 1998.

4. Institute of Transportation Engineers. *Determining Vehicle Signal Change and Clearance Intervals.* Washington, DC: Institute of Transportation Engineers, 1994.

5. Institute of Transportation Engineers. *Traffic Engineering Handbook,* 5th Ed. James L. Pline, ed. Institute of Transportation Engineers, 1999.

APPENDIX

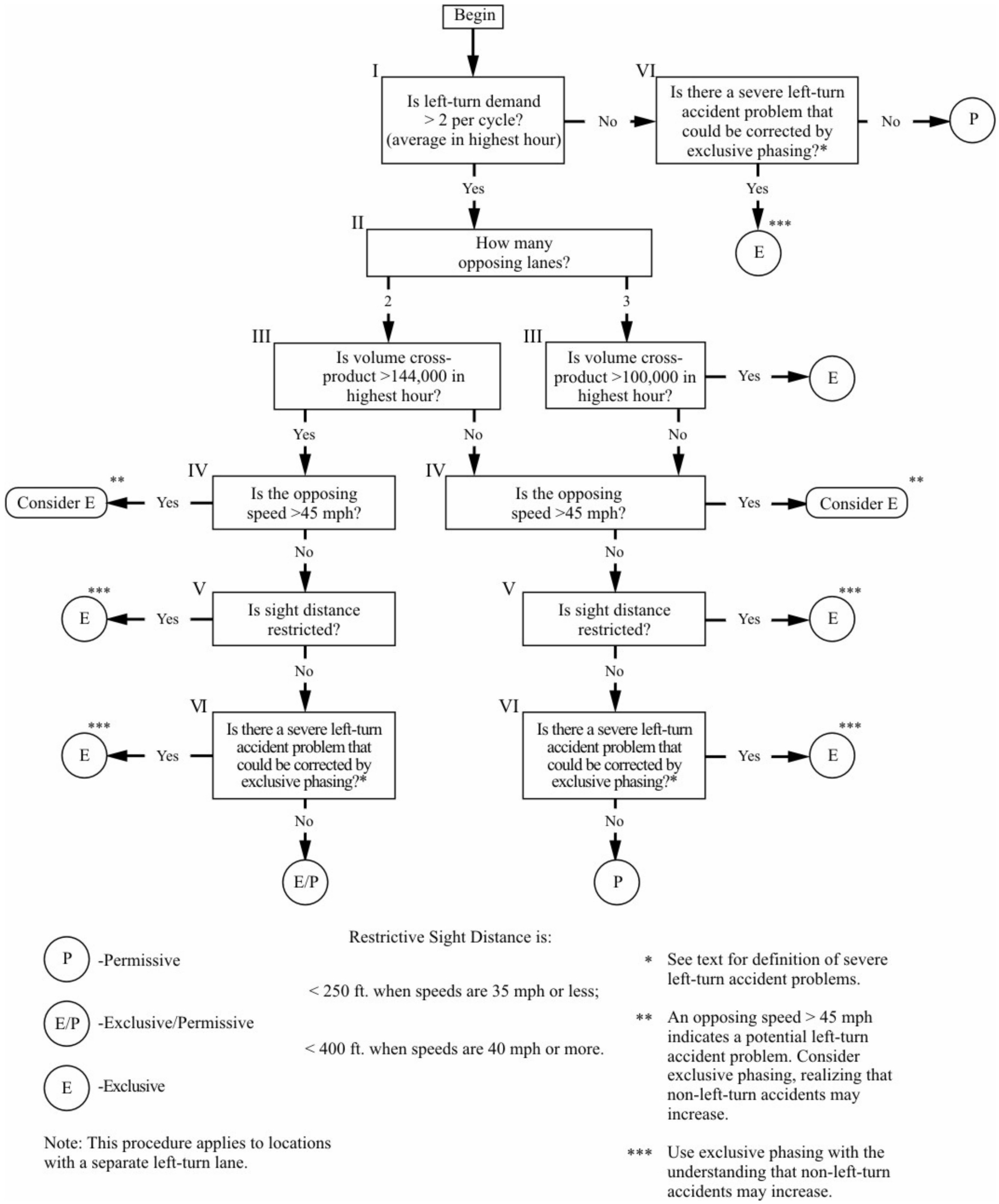

Figure A-1. Recommended Procedure for Determining Type of Left-Turn Phasing

From J. E. Upchurch. Guidelines for Selecting Type of Left-turn Phasing. In *Transportation Research Record* 1069, Transportation Research Board, National Research Council, Washington, D.C., Figure 5, p. 37. Reproduced with permission.

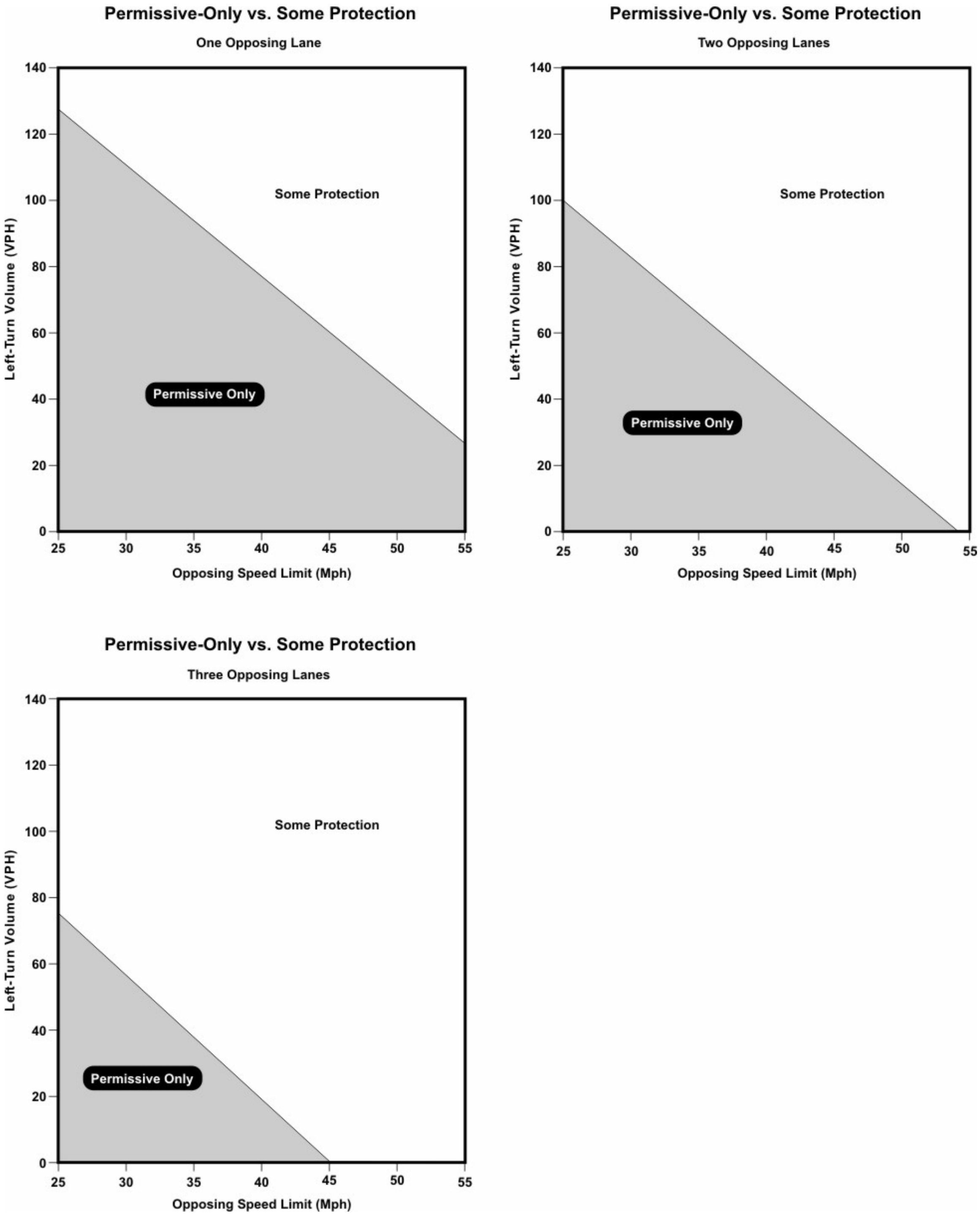

Figure A-2. Selection Criteria for Left-Turn Phasing

From Asante, S. A., S. A. Ardekani, and J. C. Williams. Selection Criteria for Left-Turn Phasing and Indication Sequence. In *Transportation Research Record* 1421, Transportation Research Board, National Research Council, Washington, D.C., 1993, Figure 4, p. 17. Reproduced with permission.

Table A - 1
Theoretical Minimum Clearance Intervals
Intersection Width (ft) = 30

Grade (%)		-10			-9			-8			-7			-6			-5 to +5			+6			+7			+8			+9			+10		
Interval		Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T
Approach Speed (mph)	20	3.2	1.7	4.9	3.1	1.7	4.8	3.0	1.7	4.7	2.9	1.7	4.6	2.8	1.7	4.5	2.5	1.7	4.2	2.2	1.7	3.9	2.2	1.7	3.9	2.2	1.7	3.9	2.1	1.7	3.8	2.1	1.7	3.8
	25	3.7	1.4	5.1	3.6	1.4	4.9	3.5	1.4	4.8	3.4	1.4	4.7	3.3	1.4	4.6	2.8	1.4	4.2	2.5	1.4	3.9	2.5	1.4	3.9	2.5	1.4	3.8	2.4	1.4	3.8	2.4	1.4	3.8
	30	4.2	1.1	5.4	4.1	1.1	5.2	4.0	1.1	5.1	3.8	1.1	5.0	3.7	1.1	4.9	3.2	1.1	4.3	2.8	1.1	4.0	2.8	1.1	3.9	2.7	1.1	3.9	2.7	1.1	3.8	2.7	1.1	3.8
	35	4.8	1.0	5.8	4.6	1.0	5.6	4.5	1.0	5.4	4.3	1.0	5.3	4.2	1.0	5.2	3.6	1.0	4.5	3.2	1.0	4.1	3.1	1.0	4.1	3.0	1.0	4.0	3.0	1.0	4.0	2.9	1.0	3.9
	40	5.3	0.9	6.2	5.1	0.9	6.0	5.0	0.9	5.8	4.8	0.9	5.6	4.6	0.9	5.5	3.9	0.9	4.8	3.5	0.9	4.3	3.4	0.9	4.2	3.3	0.9	4.2	3.3	0.9	4.1	3.2	0.9	4.1
	45	5.9	0.8	6.6	5.6	0.8	6.4	5.4	0.8	6.2	5.3	0.8	6.0	5.1	0.8	5.8	4.3	0.8	5.1	3.8	0.8	4.5	3.7	0.8	4.5	3.6	0.8	4.4	3.6	0.8	4.3	3.5	0.8	4.3
	50	6.4	0.7	7.1	6.2	0.7	6.8	5.9	0.7	6.6	5.7	0.7	6.4	5.5	0.7	6.2	4.7	0.7	5.3	4.1	0.7	4.8	4.0	0.7	4.7	3.9	0.7	4.6	3.8	0.7	4.5	3.8	0.7	4.5
	55	6.9	0.6	7.6	6.7	0.6	7.3	6.4	0.6	7.1	6.2	0.6	6.8	6.0	0.6	6.6	5.0	0.6	5.7	4.4	0.6	5.0	4.3	0.6	4.9	4.2	0.6	4.8	4.1	0.6	4.7	4.1	0.6	4.7
	60	7.5	0.6	8.1	7.2	0.6	7.8	6.9	0.6	7.5	6.7	0.6	7.2	6.5	0.6	7.0	5.4	0.6	6.0	4.7	0.6	5.3	4.6	0.6	5.2	4.5	0.6	5.1	4.4	0.6	5.0	4.3	0.6	4.9

Table A - 2
Theoretical Minimum Clearance Intervals
Intersection Width (ft) = 50

Grade (%)		-10			-9			-8			-7			-6			-5 to +5			+6			+7			+8			+9			+10		
Interval		Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T
Approach Speed (mph)	20	3.2	2.4	5.5	3.1	2.4	5.5	3.0	2.4	5.4	2.9	2.4	5.3	2.8	2.4	5.2	2.5	2.4	4.9	2.2	2.4	4.6	2.2	2.4	4.6	2.2	2.4	4.6	2.1	2.4	4.5	2.1	2.4	4.5
	25	3.7	1.9	5.6	3.6	1.9	5.5	3.5	1.9	5.4	3.4	1.9	5.3	3.3	1.9	5.2	2.8	1.9	4.7	2.5	1.9	4.4	2.5	1.9	4.4	2.5	1.9	4.4	2.4	1.9	4.3	2.4	1.9	4.3
	30	4.2	1.6	5.8	4.1	1.6	5.7	4.0	1.6	5.6	3.8	1.6	5.4	3.7	1.6	5.3	3.2	1.6	4.8	2.8	1.6	4.4	2.8	1.6	4.4	2.7	1.6	4.3	2.7	1.6	4.3	2.7	1.6	4.3
	35	4.8	1.4	6.1	4.6	1.4	6.0	4.5	1.4	5.8	4.3	1.4	5.7	4.2	1.4	5.5	3.6	1.4	4.9	3.2	1.4	4.5	3.1	1.4	4.5	3.0	1.4	4.4	3.0	1.4	4.4	2.9	1.4	4.3
	40	5.3	1.2	6.5	5.1	1.2	6.3	5.0	1.2	6.1	4.8	1.2	6.0	4.6	1.2	5.8	3.9	1.2	5.1	3.5	1.2	4.7	3.4	1.2	4.6	3.3	1.2	4.5	3.3	1.2	4.5	3.2	1.2	4.4
	45	5.9	1.1	6.9	5.6	1.1	6.7	5.4	1.1	6.5	5.3	1.1	6.3	5.1	1.1	6.2	4.3	1.1	5.4	3.8	1.1	4.8	3.7	1.1	4.8	3.6	1.1	4.7	3.6	1.1	4.6	3.5	1.1	4.6
	50	6.4	1.0	7.4	6.2	1.0	7.1	5.9	1.0	6.9	5.7	1.0	6.7	5.5	1.0	6.5	4.7	1.0	5.6	4.1	1.0	5.0	4.0	1.0	4.9	3.9	1.0	4.9	3.8	1.0	4.8	3.8	1.0	4.7
	55	6.9	0.9	7.8	6.7	0.9	7.5	6.4	0.9	7.3	6.2	0.9	7.1	6.0	0.9	6.9	5.0	0.9	5.9	4.4	0.9	5.2	4.3	0.9	5.2	4.2	0.9	5.1	4.1	0.9	5.0	4.1	0.9	4.9
	60	7.5	0.8	8.3	7.2	0.8	8.0	6.9	0.8	7.7	6.7	0.8	7.5	6.5	0.8	7.2	5.4	0.8	6.2	4.7	0.8	5.5	4.6	0.8	5.4	4.5	0.8	5.3	4.4	0.8	5.2	4.3	0.8	5.1

Table A - 3
Theoretical Minimum Clearance Intervals
Intersection Width (ft) = 70

Grade (%)		-10			-9			-8			-7			-6			-5 to +5			+6			+7			+8			+9			+10		
Interval		Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T
Approach Speed (mph)	20	3.2	3.1	6.2	3.1	3.1	6.1	3.0	3.1	6.0	2.9	3.1	6.0	2.8	3.1	5.9	2.5	3.1	5.5	2.2	3.1	5.3	2.2	3.1	5.3	2.2	3.1	5.2	2.1	3.1	5.2	2.1	3.1	5.2
	25	3.7	2.5	6.2	3.6	2.5	6.0	3.5	2.5	5.9	3.4	2.5	5.8	3.3	2.5	5.7	2.8	2.5	5.3	2.5	2.5	5.0	2.5	2.5	5.0	2.5	2.5	4.9	2.4	2.5	4.9	2.4	2.5	4.8
	30	4.2	2.0	6.3	4.1	2.0	6.1	4.0	2.0	6.0	3.8	2.0	5.9	3.7	2.0	5.8	3.2	2.0	5.2	2.8	2.0	4.9	2.8	2.0	4.8	2.7	2.0	4.8	2.7	2.0	4.8	2.7	2.0	4.7
	35	4.8	1.8	6.5	4.6	1.8	6.4	4.5	1.8	6.2	4.3	1.8	6.1	4.2	1.8	5.9	3.6	1.8	5.3	3.2	1.8	4.9	3.1	1.8	4.8	3.0	1.8	4.8	3.0	1.8	4.7	2.9	1.8	4.7
	40	5.3	1.5	6.9	5.1	1.5	6.7	5.0	1.5	6.5	4.8	1.5	6.3	4.6	1.5	6.2	3.9	1.5	5.5	3.5	1.5	5.0	3.4	1.5	4.9	3.3	1.5	4.9	3.3	1.5	4.8	3.2	1.5	4.8
	45	5.9	1.4	7.2	5.6	1.4	7.0	5.4	1.4	6.8	5.3	1.4	6.6	5.1	1.4	6.5	4.3	1.4	5.7	3.8	1.4	5.1	3.7	1.4	5.1	3.6	1.4	5.0	3.6	1.4	4.9	3.5	1.4	4.9
	50	6.4	1.2	7.6	6.2	1.2	7.4	5.9	1.2	7.2	5.7	1.2	7.0	5.5	1.2	6.8	4.7	1.2	5.9	4.1	1.2	5.3	4.0	1.2	5.2	3.9	1.2	5.1	3.8	1.2	5.1	3.8	1.2	5.0
	55	6.9	1.1	8.1	6.7	1.1	7.8	6.4	1.1	7.5	6.2	1.1	7.3	6.0	1.1	7.1	5.0	1.1	6.1	4.4	1.1	5.5	4.3	1.1	5.4	4.2	1.1	5.3	4.1	1.1	5.2	4.1	1.1	5.2
	60	7.5	1.0	8.5	7.2	1.0	8.2	6.9	1.0	7.9	6.7	1.0	7.7	6.5	1.0	7.5	5.4	1.0	6.4	4.7	1.0	5.7	4.6	1.0	5.6	4.5	1.0	5.5	4.4	1.0	5.4	4.3	1.0	5.4

Table A - 4
Theoretical Minimum Clearance Intervals
Intersection Width (ft) = 90

Grade (%)		-10			-9			-8			-7			-6			-5 to +5			+6			+7			+8			+9			+10		
Interval		Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T
Approach Speed (mph)	20	3.2	3.7	6.9	3.1	3.7	6.8	3.0	3.7	6.7	2.9	3.7	6.6	2.8	3.7	6.6	2.5	3.7	6.2	2.2	3.7	6.0	2.2	3.7	5.9	2.2	3.7	5.9	2.1	3.7	5.9	2.1	3.7	5.9
	25	3.7	3.0	6.7	3.6	3.0	6.6	3.5	3.0	6.5	3.4	3.0	6.4	3.3	3.0	6.3	2.8	3.0	5.8	2.5	3.0	5.5	2.5	3.0	5.5	2.5	3.0	5.5	2.4	3.0	5.4	2.4	3.0	5.4
	30	4.2	2.5	6.7	4.1	2.5	6.6	4.0	2.5	6.5	3.8	2.5	6.3	3.7	2.5	6.2	3.2	2.5	5.7	2.8	2.5	5.3	2.8	2.5	5.3	2.7	2.5	5.2	2.7	2.5	5.2	2.7	2.5	5.2
	35	4.8	2.1	6.9	4.6	2.1	6.8	4.5	2.1	6.6	4.3	2.1	6.5	4.2	2.1	6.3	3.6	2.1	5.7	3.2	2.1	5.3	3.1	2.1	5.2	3.0	2.1	5.2	3.0	2.1	5.1	2.9	2.1	5.1
	40	5.3	1.9	7.2	5.1	1.9	7.0	5.0	1.9	6.8	4.8	1.9	6.7	4.6	1.9	6.5	3.9	1.9	5.8	3.5	1.9	5.3	3.4	1.9	5.3	3.3	1.9	5.2	3.3	1.9	5.1	3.2	1.9	5.1
	45	5.9	1.7	7.5	5.6	1.7	7.3	5.4	1.7	7.1	5.3	1.7	6.9	5.1	1.7	6.8	4.3	1.7	6.0	3.8	1.7	5.4	3.7	1.7	5.4	3.6	1.7	5.3	3.6	1.7	5.2	3.5	1.7	5.2
	50	6.4	1.5	7.9	6.2	1.5	7.7	5.9	1.5	7.4	5.7	1.5	7.2	5.5	1.5	7.0	4.7	1.5	6.2	4.1	1.5	5.6	4.0	1.5	5.5	3.9	1.5	5.4	3.8	1.5	5.3	3.8	1.5	5.3
	55	6.9	1.4	8.3	6.7	1.4	8.0	6.4	1.4	7.8	6.2	1.4	7.6	6.0	1.4	7.4	5.0	1.4	6.4	4.4	1.4	5.7	4.3	1.4	5.7	4.2	1.4	5.6	4.1	1.4	5.5	4.1	1.4	5.4
	60	7.5	1.3	8.7	7.2	1.3	8.4	6.9	1.3	8.2	6.7	1.3	7.9	6.5	1.3	7.7	5.4	1.3	6.7	4.7	1.3	5.9	4.6	1.3	5.8	4.5	1.3	5.7	4.4	1.3	5.7	4.3	1.3	5.6

Table A - 5
Theoretical Minimum Clearance Intervals
Intersection Width (ft) = 110

Grade (%)	-10			-9			-8			-7			-6		
Interval	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T
Approach Speed (mph) 20	3.2	4.4	7.6	3.1	4.4	7.5	3.0	4.4	7.4	2.9	4.4	7.3	2.8	4.4	7.2
25	3.7	3.5	7.2	3.6	3.5	7.1	3.5	3.5	7.0	3.4	3.5	6.9	3.3	3.5	6.8
30	4.2	3.0	7.2	4.1	3.0	7.1	4.0	3.0	6.9	3.8	3.0	6.8	3.7	3.0	6.7
35	4.8	2.5	7.3	4.6	2.5	7.1	4.5	2.5	7.0	4.3	2.5	6.8	4.2	2.5	6.7
40	5.3	2.2	7.5	5.1	2.2	7.3	5.0	2.2	7.2	4.8	2.2	7.0	4.6	2.2	6.9
45	5.9	2.0	7.8	5.6	2.0	7.6	5.4	2.0	7.4	5.3	2.0	7.2	5.1	2.0	7.1
50	6.4	1.8	8.2	6.2	1.8	7.9	5.9	1.8	7.7	5.7	1.8	7.5	5.5	1.8	7.3
55	6.9	1.6	8.6	6.7	1.6	8.3	6.4	1.6	8.0	6.2	1.6	7.8	6.0	1.6	7.6
60	7.5	1.5	9.0	7.2	1.5	8.7	6.9	1.5	8.4	6.7	1.5	8.2	6.5	1.5	7.9

Grade (%)	-5 to +5			+6			+7			+8			+9			+10		
Interval	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T	Y	R	T
Approach Speed (mph) 20	2.5	4.4	6.9	2.2	4.4	6.7	2.2	4.4	6.6	2.2	4.4	6.6	2.1	4.4	6.6	2.1	4.4	6.5
25	2.8	3.5	6.4	2.5	3.5	6.1	2.5	3.5	6.0	2.5	3.5	6.0	2.4	3.5	6.0	2.4	3.5	5.9
30	3.2	3.0	6.2	2.8	3.0	5.8	2.8	3.0	5.7	2.7	3.0	5.7	2.7	3.0	5.7	2.7	3.0	5.6
35	3.6	2.5	6.1	3.2	2.5	5.7	3.1	2.5	5.6	3.0	2.5	5.6	3.0	2.5	5.5	2.9	2.5	5.5
40	3.9	2.2	6.1	3.5	2.2	5.7	3.4	2.2	5.6	3.3	2.2	5.5	3.3	2.2	5.5	3.2	2.2	5.4
45	4.3	2.0	6.3	3.8	2.0	5.7	3.7	2.0	5.7	3.6	2.0	5.6	3.6	2.0	5.5	3.5	2.0	5.5
50	4.7	1.8	6.4	4.1	1.8	5.8	4.0	1.8	5.8	3.9	1.8	5.7	3.8	1.8	5.6	3.8	1.8	5.5
55	5.0	1.6	6.6	4.4	1.6	6.0	4.3	1.6	5.9	4.2	1.6	5.8	4.1	1.6	5.7	4.1	1.6	5.7
60	5.4	1.5	6.9	4.7	1.5	6.2	4.6	1.5	6.1	4.5	1.5	6.0	4.4	1.5	5.9	4.3	1.5	5.8

Y = Yellow Change Interval = $t + V / (2a + 64.4g)$

R = Red Clearance Interval = $(W + L) / V$

T = Total Clearance Interval = $(Y + R)$

Where,

t = perception-reaction time, seconds (1 second for tables above)
V = approach speed, feet/second
a = deceleration rate, feet/second^2 (10 feet/second^2 for tables above)
g = percent of grade divided by 100 (+ for upgrade, - for downgrade)
W = width of intersection, feet
L = length of vehicle, feet (20 feet for tables above)

Table A - 6
Speed Conversion from
Miles per Hour (MPH)
to Feet per Second (FPS)

MPH	FPS	MPH	FPS
15	22.00	45	66.00
20	29.33	50	73.33
25	36.67	55	80.67
30	44.00	60	88.00
35	51.33	65	95.33
40	58.67	70	102.67

To convert MPH to FPS multiply by 1.467

Metropolitan Government of Nashville and Davidson County Department of Public Works, Engineering Division